Transient Trapping of Helium by Bubble Formation in Liquid Gallium

Don Cowgill, Rion Causey, Kristin Hertz, Dan Morse
Sandia National Laboratories, Livermore, CA 94550

PFC Meeting, Livermore, California
December 6-8, 2004

- Flowing Liq. Metals have potential to pump He by bubble formation.
- Sandia's Bubbles in Liquid Metals (BLM) code predicts significant bubble nucleation and growth in liquid metals.
- Experimental Goal: Test and benchmark the model at low flux.

- Status of Penning Trap Experiments:
  Re-emission mini-trap -- preliminary results indicate bubbles
  He profiling trap -- experiments in progress

The BLM code follows self-nucleation, growth and coalescence of He bubbles.

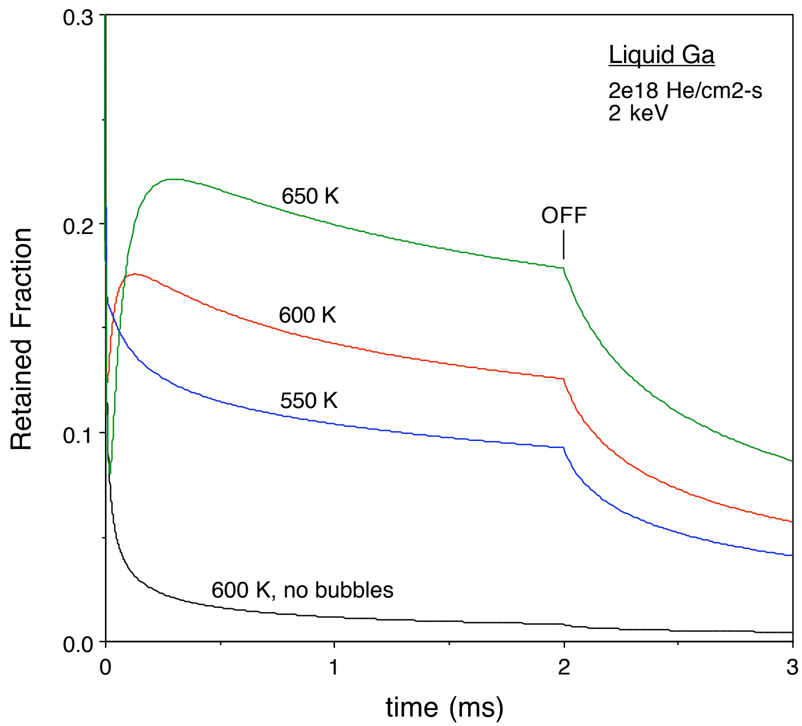
- Modification of Sandia's Nano-Bubble Evolution (NBE) model for He bubbles in aging metal tritides.
  - Bubbles are nucleated by self-trapping (He-He encounter).
  - Bubble pressure is determined by surface tension ($2g/r_N$).
  - Bubbles diffuse according to Stokes-Einstein ($D_N=kT/6phr_N$).

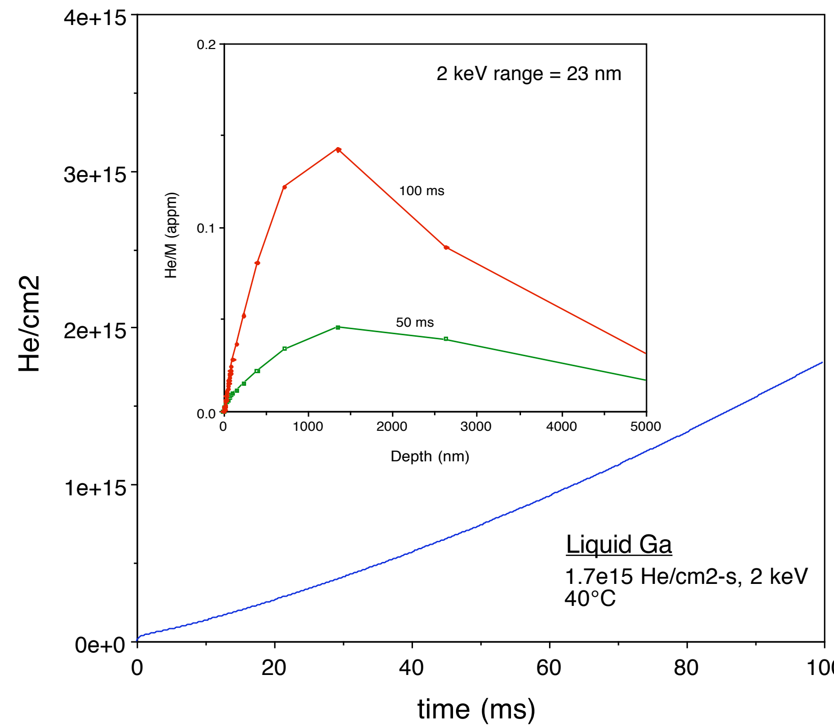
- BLM uses coupled differential equations with source and loss terms to follow concentration depth profiles of bubble groups ($N=2^{n-1}$).
  - He implantation depth profile by SRIM code
  - Bubbles grow by He atom accumulation and by coalescence.
  - Bubbles dissociate according to their stability E_N

- Result: Low concentrations of large, slowly-diffusing bubbles occur well beyond the implant range.

BLM predicts high He concentrations at both high and low flux conditions.

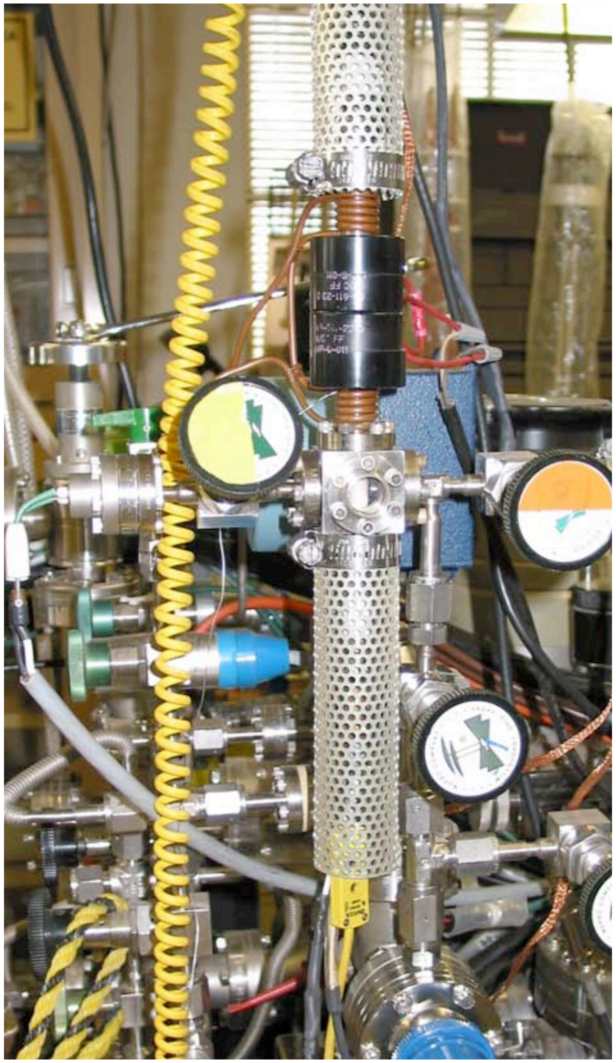
- Cumulative He retention reaches 20% under divertor-like conditions.

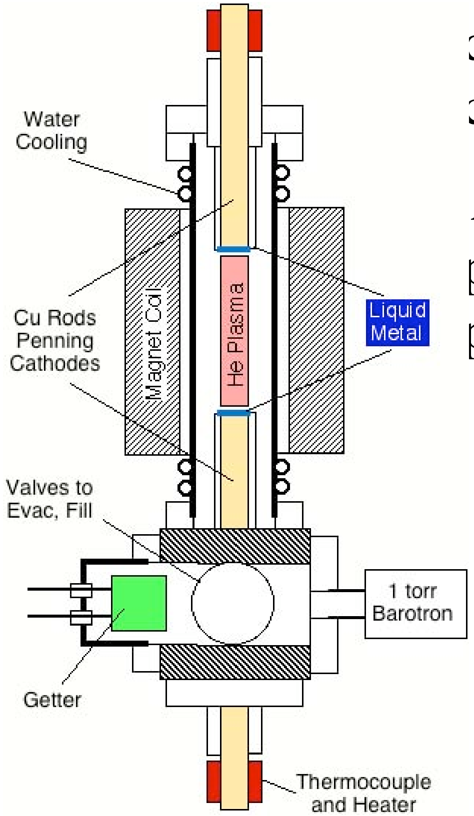




- He concentrations of 10^{-4} He/Ga also occur under laboratory-like (long, low flux) exposures.

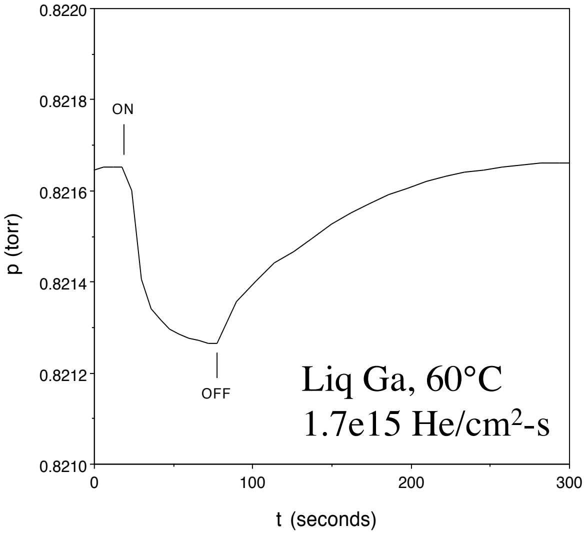
Our mini-Penning experiment is examining dynamic retention by pressure change.





- Gettered Penning discharge with liquid metal cathodes.

A small gas volume (40cc) produces high sensitivity to pumping by the liq. metal.



Sandia National Laboratories

Magnitude and temperature dependence of the retention indicates bubble formation.

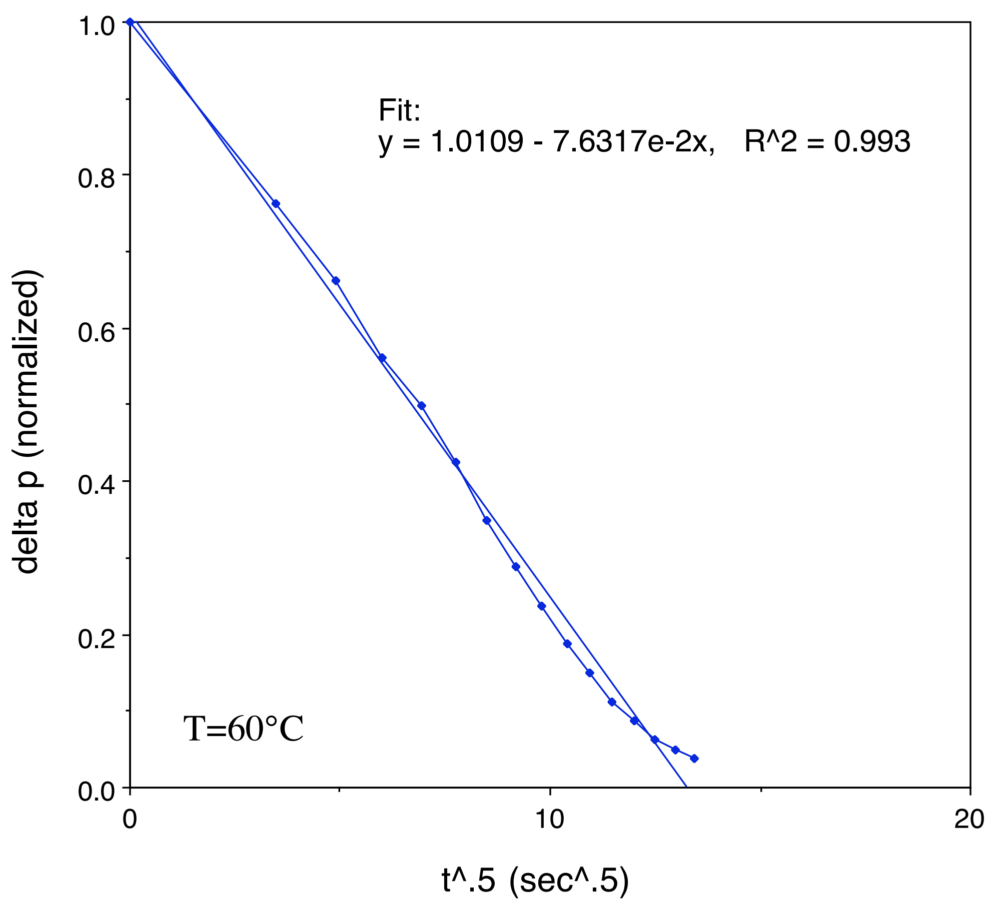
- Observed magnitude is
  - more than calculated for atom diff. profile.
  - in agreement with BLM code.

  (Code has not been run long enough to reach equilibrium.)

- Observed magnitude increases with T
  - *opposite* to normal diffusion behavior,
  - *in agreement* with enlarging bubbles.

	Temp(°C)	He quantity
Observed (from Δp)	60	6e14 He
	90	1e15
	125	3e15
Calculated in diff profile	125	1.5e12
	325	5.4e11
Code prediction with bubbles	40	1e14 at 0.1s
	225	(1e13 at 7ms)
	325	(2e13 at 7ms)

The re-emission time constant is also consistent with bubble formation.



- Draining of L-thick slab has approx. $t^{1/2}$ time dependence:
  $M(t)/M(0) \approx (4Dt/\pi L^2)^{1/2}$

  - With estimated Ga film thickness of $L \approx .25$ mm, fit gives $D_{eff} \approx 3\text{x}10^{-6}$ cm^2/s

- Self-diffusion in Liq Ga:
  $D_{SD}(55°C) = 2.6\text{x}10^{-5}$ cm^2/s

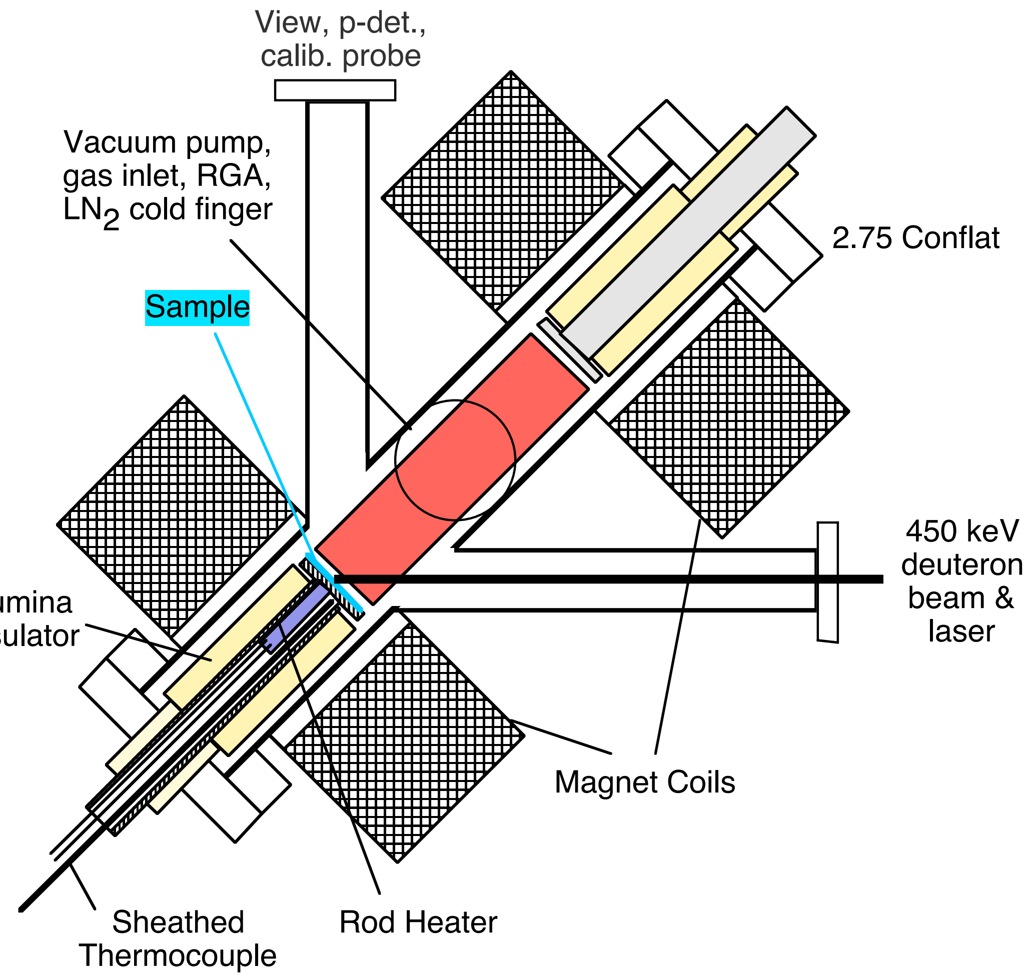
- The 10x lower diffusivity requires
  $Dia_{bubble} = 10\ Dia_{Ga} \approx 2.7$ nm
  or about 4000 He/bubble.

Sandia National Laboratories

Our second, larger Penning experiment is verifying He buildup in the liquid metal.

- ^3He Penning discharge produces 10^{17} He/cm^2-s on liquid metal at 1-2 keV.
    - Liquid metal covers one trap (cathode) plate.

- ^3He buildup in liquid metal is measured by real time $^3He(d,p)^4He$ NRA.
    - Use of d^+ beam requires shielded accelerator and remote discharge control.



Sandia National Laboratories

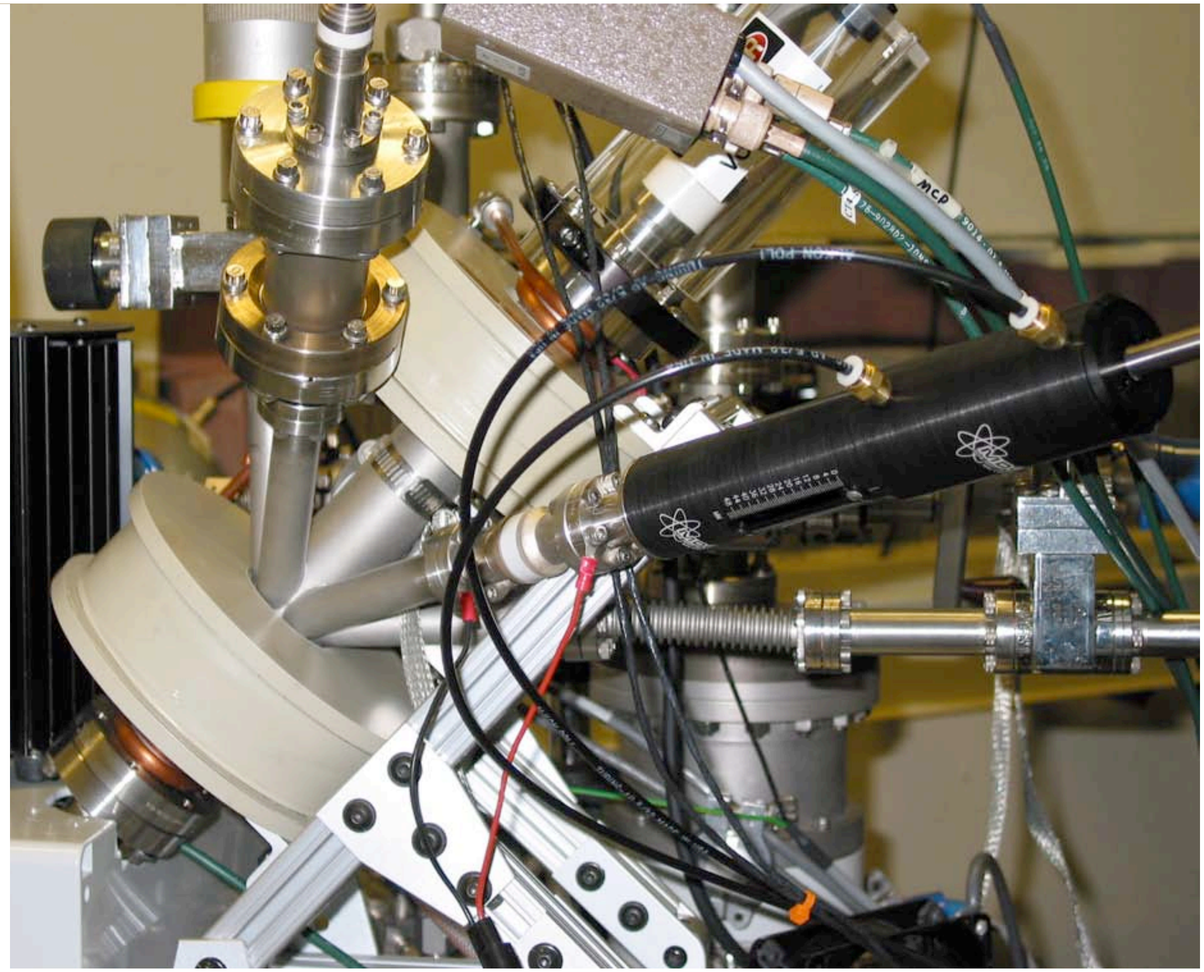
First tests of the complete system with liquid Ga occurred last week.

Observations:

- ^{3}He(d,p) count rate:
  Background < .1 Hz
  15 mtorr ^{3}He ≈ 0.5 Hz
  At 2 mA/cm^{2} ≈ 8 Hz

- Laser reflection showed liquid surface became turbulent around 2 mA/cm^{2}.
  - Flux threshold!

- After long discharge, count rate remained high & surface dulled.
  - Ga contaminated.



Sandia National Laboratories

Summary of experimental results:

- Experiments with mini-Penning trap support He bubble formation under even modest plasma fluxes.

  Magnitude of pumping effect is
  - too large for diffusion profile.

  Pumping increases with temperature:
  - opposite to diffusive retention
  - consistent with growing bubbles.

  Long time constant for re-emission
  - indicates 10x slower diffusive release
  - is consistent with 4000 atom (3nm) bubbles.

- Initial test with the accelerator-based Penning discharge show He retention consistent with bubbles and BLM calculations.
  - ^{3}He(d,p) count rate gives ~10^{-4} He/Ga in top 2 μm.
  - Observed turbulence threshold (not yet predicted).

Experimental Plans:

- Add improvements to accelerator-based experiment.
  - Control contamination: Clean system by GDC.
  - Add *in-situ* sample film wiper
  - Reduce sample thickness variation

- Acquire model testing data for liquid Ga using parameter space.
  - Vary temperature, flux
  - Examine turbulence (bubbling) threshold
    (Look for BLM code predictions of bubble growth runaway, …)

- Examine deuterium bubble formation in liquid Ga.
  - Run deuterium Penning and measure with ^{3}He.
  - Look for turbulence threshold

- Repeat experiments using liquid Li and Sn.